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Bacterial community changes in a glacial-fed Tibetan lake are correlated with glacial melting

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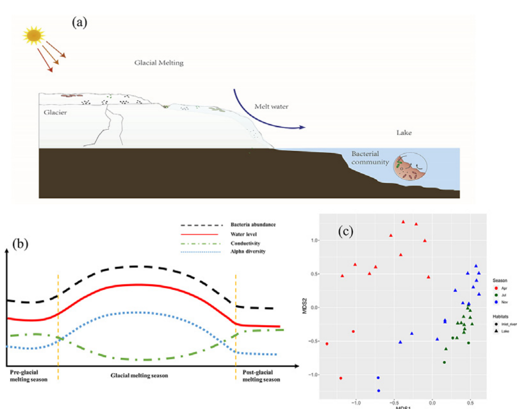
HIGHLIGHTS

- Bacterial communities exhibited obvious seasonal trends and significantly differed among the seasons.
- Bacterial communities changed along the gradient of conductivity concentration.
- The bacterial community composition, diversity and abundance were intensively affected by seasonal glacial melting.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change-induced glacial melting is a global phenomenon. The effects of climate change-induced melting on the microbial ecology in different glacial-fed aquatic systems have been well illuminated, but the resolution of seasonal dynamics was still limited. Here, we studied bacterial community composition and diversity in a glacial-fed Tibetan lake, Lake Ranwu, to elucidate how glacial-fed aquatic ecosystems respond to the seasonal glacial melting. Obvious seasonal variations of bacterial dominant groups were found in Lake Ranwu and inlet rivers. In April, the majority of OTUs belonged to the Bacteroidetes, Actinobacteria and Proteobacteria. The Proteobacteria increased to the most abundant phylum in July and November, while the Bacteroidetes and Actinobacteria decreased about 50% over seasons. Most key discriminant taxa of each season's community strongly associated with specific environmental variables, suggesting their adaptation to seasonal environments. Bacterial alpha diversity varied among seasons and exhibited strongly negative correlations with conductivity. Conductivity was the major driving force in determining the seasonal variation of bacterial community composition. Fluctuated conductivity was one of the consequences of seasonal melting of glaciers. This study offered evidence for the unique seasonal dynamics pattern of bacterial communities responding to glacial melting.

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Moreover, this study may provide a reference for assessing the long-term effects of glacial retreat on glacial-fed aquatic ecosystems.

1. Introduction

Glaciers are sensitive indicators of climate change (Moore et al., 2009). Continuing glacial melting is one of the most prominent signals of global climate change (Stocker et al., 2013). Glacial melting increases the meltwater immediately, but decreases the amount of meltwater in the long term with the coverage of glacial area decreasing. Shifts in the water supply influence the physicochemical characteristics of downstream ecosystems, which subsequently effect on microbial communities, leading to the total loss of microbial biodiversity in glacier-fed lakes/streams (Brown et al., 2007; Milner et al., 2009; Solomina et al., 2015; Milner et al., 2017). Bacterial diversities in glacial-fed lakes are significantly decreased with turbidity owing to the dilution of the lake water by the melting of glaciers (Peter and Sommaruga, 2016). Wilhelm et al. (2013) have found that the shrinking of glaciers increased bacterial alpha diversity but reduced bacterial beta diversity in glacial melt-fed streams across 26 alpine glaciers (Wilhelm et al., 2013). These studies make clear that glacial melting drives the spatial variability of bacterial community composition and diversity.

Glacial melting has a profound influence on glacial-fed aquatic systems over a timescale of days to millennia (Moore et al., 2009). Therefore, the response of glacial-fed aquatic ecosystems to glacial melting-induced environmental changes will have varied through time. At the seasonal timescale, glaciers melt in summer and increase the meltwater quantities. During the melting season, as meltwater quantity increase, dilution of dissolved salt concentrations is observed (Anderson, 2007; Milner et al., 2009). Seasonal shifts in the hydrological regime in the glacial-fed aquatic systems will alter the physicochemical properties to which microbial communities have adapted. However, how microbial communities in the glacial-fed aquatic systems respond to seasonal glacier-induced environmental changes remains unclear. Thus, time-series studies of the current melting of glaciers could be beneficial research strategies to understand how the long term glacial melting affects the ecosystem.

Previous studies suggest that bacterial communities in the glacial-fed aquatic systems are assembled by deterministic processes such as environmental filtering (Wilhelm et al., 2013; Milner et al., 2017). The concept of environmental filtering proposes that changes in species abundances and diversity patterns along environmental gradients, such as conductivity, temperature, and chlorophyll *a* (Chl *a*) concentration, based on their traits and adaptations to prevailing environmental conditions (Lebrija-Trejos et al., 2010; Lindstrom and Langenheder, 2012; Sommer et al., 2014). Glacier-fed lakes/streams are examples of harsh environments and associate with low temperature, nutrient deficiency and low taxonomic richness (Jacobsen and Dangles, 2012; Jacobsen et al., 2012). It may therefore be that harsh environments imposed strong environmental filtering on bacterial communities in the glacial-fed aquatic systems.

The Tibetan Plateau contains the largest area of glaciers outside the polar regions with a total area of 49,873 km^2 (Immerzeel et al., 2010; Yao et al., 2010). The Tibetan Plateau has the largest lake group in the Asian continent, where the lakes respond sensitively to climate change. Glaciers are continuously melting, resulting in expanding glacial-fed lake area in this region (Xin et al., 2009; Yang et al., 2008; Yao et al., 2007). In the past few decades, climate warming-induced glacial melting has strongly affected the environment and aquatic ecosystems on the Tibetan Plateau (Chen et al., 2013; Yao, 2010). The Tibetan Plateau serves as the main water storage reservoir for South and East Asia (Immerzeel et al., 2010), it is especially important to understand the influence of seasonal glacial melting on microbial communities in downstream glacial-fed lakes in this region.

Here, we explored the seasonal variations in bacterial community composition and diversity in Lake Ranwu, which is located in the proximity of rapidly melting glaciers in the southeastern Plateau. This study aims to obtain an in-depth understanding of seasonal changes in glacial-fed bacterial communities and their response to glacial melting. Studies of the geomorphology and remote sensing data of the Lake Ranwu catchment show that the glacial coverage decreased dramatically and the lake area expanded annually in the last 25 years (Yao et al., 2010). Because the high discharge during summer ablation resulted in an increase input of microbes into glacial melt-fed lakes and low dissolved salt concentrations in downstream, we hypothesized that bacterial diversity increased with the discharge of glacial melting in Lake Ranwu. The environmental harshness of a specific lake site is highly dependent on its distance from the glacier and the size of the glacier meltwater discharge (Moore et al., 2009). Given that many glacial-fed lakes generally characterized by low nutrients, temperature and productivity, we postulated that environmental filtering played a key role in shaping bacterial community composition and diversity in Lake Ranwu.

2. Materials and methods

2.1. Study area

Lake Ranwu (96°30′~97°10′ E, 29°00′~29°50′ N, 3920 m above sea level) is a glacial-fed lake located in the southeast of the Tibetan Plateau (Fig. 1). The lake is braided channel shape, with a total length of 29 km and an average width of about 800 m (Xin et al., 2009). Lake Ranwu is divided into three major areas: the upper, intermediate, and downstream. The Quchihe (QCH), Zhongkongnongba (ZKNB) and Renongba (RNB) rivers are the primary sources of water to Lake Ranwu (Fig. 1). The upper area is located close to the glacial river QCH and the intermediate area is located close to the ZKNB river. Finally, water from the RNB river and from the intermediate area mixes in the downstream area. The source of the QCH River is melt water mainly from the Yanong, Xirinongpu and Zuoqiupu Glaciers (Ju et al., 2015). The QCH River, as the largest inflow and a glacial melt river, has an important impact on the water level and hydrological characteristics of Lake Ranwu (Ju et al., 2015).

2.2. Field sampling and physiochemical analyses

Sampling was carried out in spring (14th–15th, April, the pre-glacial melting season), summer (14th–15th, July, the glacial melting season), and autumn (14th–15th, November, the post-glacial melting season) in 2012. As shown in Fig. 1, water samples were collected from the upper (R1), intermediate (R2), and downstream (R3) areas of Lake Ranwu and three inlet rivers (QCH, ZKNB and RNB). Lake samples were collected from the different depths (0.5, 5, 10, 15, 20 and 25 m) of the water column, and river samples were collected from surface (0.5 m) (Table S1).

The concentrations of dissolved oxygen (DO) and chlorophyll *a* (Chl *a*), pH, conductivity (Cond) and water temperature (T) were monitored in situ with a multi-probe Water Quality Sonde (Hydrolab DS5, Hach, USA). For assessing the bacterial community composition, approximately 1 L water were collected with a Schindler sampler and filtered onto a 0.22 μm polycarbonate membrane (Millipore, USA).